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Deflation at Turnaround for Oscillatory Cosmology

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Abstract

It is suggested that dark energy in a brane world can help reconcile an infinitely cyclic cosmology with the second law of thermodynamics. A cyclic cosmology is described, in which dark energy with constant equation of state leads to a turnaround at finite future time, when entropy is decreased by a huge factor equal to the inverse of its enhancement during the initial inflation. Thermodynamic consistency of cyclicity requires the arrow of time to reverse during contraction. Entropy reduction in the contracting phase is infinitesimally smaller than entropy increase during expansion.

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Introduction

One of the oldest questions in theoretical cosmology is whether an infinitely oscillatory universe which avoids an initial singularity can be consistently constructed. As realized by Friedmann [1] and especially by Tolman [2, 3] one principal obstacle is the second law of thermodynamics which dictates that the entropy increases from cycle to cycle. If the cycles thereby become longer, extrapolation into the past will lead back to an initial singularity again, thus removing the motivation to consider an oscillatory universe in the first place. This led to the abandonment of the oscillatory universe by the majority of workers.

Nevertheless, an oscillatory universe is an attractive alternative to the Big Bang. One new ingredient in the cosmic make-up is the dark energy discovered only in 1998 and so it is natural to ask whether this new component in the Friedmann equation can avoid the difficulties with entropy which have dogged previous attempts.

Some work has been started to exploit the dark energy in allowing cyclicity possibly without apparently the need for inflation in [4–7]. Another new ingredient is the use of branes and a fourth spatial dimension as in [8–11] which have examined the consequences for cosmology. The Big Rip and replacement of dark energy by modified gravity have been explored in [12, 13].

If the dark energy has a super-negative equation of state, $\omega_\Lambda = p_\Lambda/\rho_\Lambda < -1$, it leads to a Big Rip at a finite time where there exist extraordinary conditions with regard to density and causality as one approaches the Big Rip. In the present article we explore whether these exceptional physical conditions can assist in providing a truly infinitely-cyclic entropy density in an oscillatory universe of time periodicity $t = t \pmod{\tau}$.

We shall consider the situation where if, as we approach the Big Rip, the expansion stops just short of the rip and there is a turnaround at $t = t_T \pmod{\tau}$ when the scale factor is deflated to a very tiny fraction (f in our notation) of itself. For the deflation there is a consistency condition, written in Eq.(10). Entropy is extensive so a fraction $(1 - f^3)$ is jettisoned at turnaround. One key ingredient is that the turnaround takes place a sufficiently short time before the Big Rip would have occurred, at a time when the universe is fractionated into many causal patches [13].

We then proceed to investigate the contraction phase which occurs with a very much smaller universe than in the expansion phase. A bounce at $t = \tau \pmod{\tau}$ takes place a short time before what would have been the Big Bang. Then, immediately after the bounce, entropy is injected as usual by inflation [14] where the scale factor is enhanced by factor E and hence entropy by E^3 . Inflation is thus an essential part of the present scenario which is one distinction from the work of [4–7].

For cyclicity of the entropy, $S(t) = S(t + \tau)$ to be consistent with thermodynamics it is insufficient that the huge inflationary enhancement E^3 be completely compensated by deflation at turnaround. Additionally, it is necessary for the thermodynamic arrow of time to reverse during contraction. This is one shortcoming of the proposal. The decrease in entropy during contraction is infinitesimal, being at most 10^{-84} (sic) of the entropy increase during expansion. The parameters f and E are related by consistency of the

expansion and contraction.

A second possible shortcoming of the proposal is the persistence of spacetime singularities in cyclic cosmologies [15] which we do not address.

This paper is published because our discussion seems to give a plausible realization of the oscillatory universe originally sought in [1–3] whose shortcomings can hopefully be evolved by others into a more convincing scenario. The shortcomings are discussed again in the Final Discussion section.

Friedmann Equation for Expansion phase

Let the period of the Universe be designated by τ and the bounce take place at $t = 0 \pmod{\tau}$ and turnaround at $t = t_T \pmod{\tau}$. Thus the expansion phase is for times $0 < t < t_T \pmod{\tau}$ and the contraction phase corresponds to times $t_T < t < \tau \pmod{\tau}$.

We shall employ the following Friedmann equation for the *expansion* period $0 < t < t_T \pmod{\tau}$:

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = \frac{8\pi G}{3} \left[\left(\frac{(\rho_\Lambda)_0}{a(t)^{3(\omega_\Lambda+1)}} + \frac{(\rho_m)_0}{a(t)^3} + \frac{(\rho_r)_0}{a(t)^4} \right) - \frac{\rho_{total}(t)^2}{\rho_c} \right] \quad (1)$$

or, more succinctly,

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = \frac{8\pi G}{3} \rho_{total}(t) \left[1 - \frac{\rho_{total}(t)}{\rho_c} \right] \quad (2)$$

where the scale factor is normalized to $a(t_0) = 1$ at the present time $t = t_0 \simeq 14Gy$.

To explain the notation, $(\rho_i)_0$ denotes the value of the density ρ_i at time $t = t_0$. The first two terms are the dark energy and total matter (dark plus luminous) satisfying

$$\Omega_\Lambda = \frac{8\pi G(\rho_\Lambda)_0}{3H_0^2} = 0.72 \quad \text{and} \quad \Omega_m = \frac{8\pi G(\rho_m)_0}{3H_0^2} = 0.28 \quad (3)$$

where $H_0 = \dot{a}(t_0)/a(t_0)$. The third term in the Friedmann equation is the radiation density which is now $\Omega_r = 1.3 \times 10^{-4}$. The final term $\sim \rho_{total}(t)^2$ is derivable from the Randall-Sundrum set-up [8, 9, 11]; we use a negative sign arising either from a timelike extra dimension or, preferably, from a negative brane tension. $\rho_{total} = \sum_{i=\Lambda, m, r} \rho_i$. As the turnaround is approached, the only significant terms in Eq.(1) are the first (where $\omega_\Lambda < -1$) and the last. As the bounce is approached, the only important terms in Eq.(1) are the third and the last.

In particular, the final term of Eq. (1), $\sim \rho_{total}(t)^2$, arising from the brane set-up is insignificant for almost the entire cycle but becomes dominant as one approaches $t \rightarrow t_T \pmod{\tau}$ for the turnaround and again for $t \rightarrow \tau \pmod{\tau}$ approaching the bounce.

Turnaround Compared to Big Rip

Let us assume for algebraic simplicity $\omega_\Lambda = -4/3 = \text{constant}$. This value is already almost excluded by WMAP3 [16] but to begin we are not aiming not at realistic cosmology but at consistency of infinite cyclicity. More realistic values will be discussed elsewhere.

The approach to the Big Rip will follow that discussed in [12, 13]. With the value $\omega_\Lambda = -4/3$ we learn from [12] that the time to the Big Rip is $(t_{rip} - t_0) = 11\text{Gy}(-\omega_\Lambda - 1)^{-1} = 33\text{Gy}$ which is, within one second, when turnaround occurs at $t = t_T$. So if we adopt $t_0 = 14\text{Gy}$ then $t_T = t_0 + (t_{rip} - t_0) = (14 + 33)\text{Gy} = 47\text{Gy}$.

From the analysis in [12, 13] the time when a system becomes gravitationally unbound corresponds approximately to the time when the growing dark energy density matches the mean density of the bound system. For a “typical” object like the Earth (or a hydrogen atom where the mean density happens to be about the density of water $\rho_{H_2O} = 1\text{g/cm}^3$ since $10^{-24}\text{g}/(10^{-8}\text{cm})^3 = 1\text{g/cm}^3$) water’s density ρ_{H_2O} is an unlikely but practical unit for cosmic density in the oscillatory universe.

With this in mind, for the simple case of $\omega = -4/3$ we see from Eq.(1) that the dark energy density grows proportional to the scale factor $\rho_\Lambda(t) \propto a(t)$ and so given that the dark energy at present is $\rho_\Lambda \sim 10^{-29}\text{g/cm}^3$ it follows that $\rho(t_{H_2O}) = \rho_{H_2O}$ when $a(t_{H_2O}) \sim 10^{29}$.

So the next step, equally straightforward, is to estimate the time t_{H_2O} when this occurs. If we take the Friedmann equation with only dark energy

$$\left(\frac{\dot{a}}{a}\right)^2 = H_0^2 \Omega_\Lambda a^{-\beta} \quad (4)$$

with $\beta = 3(1 + \omega)$, then the scale factor evolves as

$$a(t) = \left[\frac{2}{3H_0\sqrt{\Omega_\Lambda}(-1 - \omega)(t_{rip} - t)} \right]^{-\frac{2}{3(1+\omega)}} \quad (5)$$

and, for later use, it follows that

$$\frac{a(t_1)}{a(t_2)} = \left(\frac{(t_{rip} - t_2)}{(t_{rip} - t_1)} \right)^{-\frac{2}{3(1+\omega)}} \quad (6)$$

When we again specialize to $\omega = -4/3$ as illustration and require as before $\rho_\Lambda(t_{H_2O}) = \rho_{H_2O}$ then $a(t_{H_2O}) = 10^{29}$ and from Eq.(6) it follows that

$$\frac{a(t_{H_2O})}{(a(t_0) = 1)} = \left(\frac{(t_{rip} - t_0)}{(t_{rip} - t_{H_2O})} \right)^2 \quad (7)$$

so that $(t_{rip} - t_{H_2O}) = 33Gy \times 10^{-14.5} \simeq 10^{3.5}s \sim 1$ hour.

[These values are sensitive to ω : if we choose $\omega = -1.1$ the corresponding results are $(t_{rip} - t_0) = 110Gy$ and $(t_{rip} - t_U) = 5.25My$.]

Returning to the case $\omega = -4/3$, it will be useful to consider a more general critical density $\rho_c = \eta\rho_{H_2O}$, since there is nothing special about ρ_{H_2O} and to compute the time $(t_{rip} - t_\eta)$ such that $\rho_\Lambda(t_\eta) = \rho_c = \eta\rho_{H_2O}$. Similarly to Eq. (7), we then find

$$\frac{a(t_\eta)}{(a(t_0) = 1)} = \left(\frac{(t_{rip} - t_0)}{(t_{rip} - t_\eta)} \right)^2 \quad (8)$$

That is, using $a(t_\eta) = 10^{29}\eta$,

$$(t_{rip} - t_\eta) = (t_{rip} - t_0)10^{-14.5}\eta^{-1} \simeq \eta^{-1}\text{hours} \quad (9)$$

which is the required result.

Deflation at Turnaround.

A key ingredient in our cyclic model is that at turnaround $t = t_T \pmod{\tau}$ our universe deflates dramatically with scale factor $a(t_T)$ shrinking to $\hat{a}(t_T) = fa(t_T)$ where $f < 10^{-28}$.

This jettisoning of almost all, a fraction $(1-f)$, of the accumulated entropy is permitted by the exceptional causal structure of the universe. We shall show later that in Eq. (9) the parameter η satisfies $\eta > 10^{27}$ (see Eq.(24)) which implies the unimaginable dark energy density at turnaround of $\rho_\Lambda(t_T) > 10^{27}\rho_{H_2O}$. By the time the dark energy density reaches such a value, according to the Big Rip analysis of [12, 13] the smallest known bound systems of particles have become unbound. Additionally the constituents will be causally disconnected meaning that if the expansion had, instead, continued to the Big Rip the particles could no longer causally communicate [13].

The Hubble parameter H for deflation at $t = t_T \pmod{\tau}$ satisfies

$$\int_{a(t_T)}^{\hat{a}(t_T)} H da = - \int_{\hat{a}(\tau)}^{a(\tau)} H da \quad (10)$$

where the right hand side refers to inflation at $t = \tau \pmod{\tau}$. We do not discuss here the brane dynamics leading to Eq.(10) but such a condition ^{#1} is necessary for true periodicity.

Friedmann Equation for Contraction Phase.

The contraction phase occurs for the period $t_T < t < \tau \pmod{\tau}$. The scale factor for the contraction phase will be denoted by $\hat{a}(t)$ while for time we use always the same linear time t subject to the periodicity $t + \tau \equiv t$.

At the turnaround we retain a fraction f^3 of the entropy with $\hat{a}(t_T) = fa(t_T)$ and for the contraction phase the Friedmann equation is

$$\left(\frac{\dot{\hat{a}}(t)}{\hat{a}(t)}\right)^2 = \frac{8\pi G}{3} \left[\left(\frac{(\hat{\rho}_\Lambda)_0}{\hat{a}(t)^{3(\omega_\Lambda+1)}} + \frac{(\hat{\rho}_m)_0}{\hat{a}(t)^3} + \frac{(\hat{\rho}_r)_0}{\hat{a}(t)^4} \right) - \frac{\hat{\rho}_{total}(t)^2}{\rho_c} \right] \quad (11)$$

where we have defined

$$\hat{\rho}_i(t) = \frac{(\rho_i)_0 f^{3(\omega_i+1)}}{\hat{a}(t)^{3(\omega_i+1)}} = \frac{(\hat{\rho}_i)_0}{\hat{a}(t)^{3(\omega_i+1)}} \quad (12)$$

Let us define landmarks in the contraction phase at times t'_0 and t'_{eq} defined by obvious analogy with expansion

$$\hat{\rho}_\Lambda(t'_0) = \hat{\rho}_m(t'_0)(\rho_\Lambda)_0/(\rho_m)_0 \quad (13)$$

and

$$\hat{\rho}_r(t'_{eq}) = \hat{\rho}_m(t'_{eq}) \quad (14)$$

The period τ will be set by $\rho_c = \text{maximum } (\hat{\rho}_i(\tau))_{i=\Lambda, m, r}$. The maximum will generally be for the most positive ω_i .

For the contraction from $t = t_T$ to the time $t = t'_0$ the Friedmann equation is dominated by the first term on the R.H.S. of Eq.(11):

$$\dot{\hat{a}}(t) = -\sqrt{\frac{8\pi G(\hat{\rho}_\Lambda)_0}{3}} \hat{a}^{3/2} \quad (15)$$

Integration of Eq. (15) from $t = t_T$ to $t = t'_0$ and using $\hat{a}(t'_0) \ll \hat{a}(t_T)$ gives

$$\hat{a}(t'_0) = \frac{4f}{\Omega_\Lambda H_0^2} \frac{1}{(t'_0 - t_T)^2} = f \quad (16)$$

^{#1}Presumably the complete five-dimensional brane-world calculation will reveal that as the Big Rip is approached a transition $a(t_T) \rightarrow \hat{a}(t_T)$ is dictated by energy considerations. We do not pursue the calculation here but merely suggest the result of a more complete treatment.

Using the definition of t'_0 from Eq. (13) results in $\hat{a}(t'_0)^4 = f^4(\rho_m)_0/(\rho_\Lambda)_0$ and

$$(t'_0 - t_T) \simeq \frac{2}{(\sqrt{\Omega_\Lambda})H_0} \sim 33Gy \quad (17)$$

using $H_0 = 70km/s/Mpc$ and $1Mpc = 3.1 \times 10^{19}km$, hence $H_0^{-1} \simeq 14Gy$.

The second stage of the contraction is from $t = t'_0 \pmod{\tau}$ to $t = t'_{eq} \pmod{\tau}$ controlled by

$$\dot{\hat{a}}(t) = -\sqrt{\frac{8\pi G(\hat{\rho}_m)_0}{3}} \hat{a}^{-1/2} \quad (18)$$

Integration of Eq. (18) from $t = t'_0$ to $t = t'_{eq}$ and using $\hat{a}(t'_{eq}) \ll \hat{a}(t'_0)$ gives

$$\hat{a}(t'_{eq}) = \frac{(\hat{\rho}_r)_0}{(\hat{\rho}_m)_0} = 5 \times 10^{-4}f \quad (19)$$

Using the definition of t'_{eq} from Eq. (14) results in

$$(t'_{eq} - t'_0) \simeq \frac{2}{3(\sqrt{\Omega_m})H_0} \sim 13Gy \quad (20)$$

The third and final stage of contraction is from $t = t'_{eq} \pmod{\tau}$ to the bounce at time $t = \tau \pmod{\tau}$ which is radiation dominated with

$$\dot{\hat{a}}(t) = -\sqrt{\frac{8\pi G(\hat{\rho}_r)_0}{3}} \hat{a}^{-1} \quad (21)$$

Integration of Eq. (21) from $t = t'_{eq}$ to $t = \tau$ and using $\hat{a}(\tau) \ll \hat{a}(t'_{eq})$ gives

$$(\tau - t'_{eq}) = \frac{1.25 \times 10^{-7}}{(\sqrt{\Omega_r})H_0} \simeq 150,000y \quad (22)$$

Bounce at $t = \tau \pmod{\tau}$

As a estimated time $t = \tau \pmod{\tau}$ for the bounce, the contraction scale is given, using $\rho_c = \eta\rho_{H_2O}$, from Eq. (1) as

$$a(\tau)^4 = \left(\frac{(\rho_r)_0}{\eta\rho_{H_2O}} \right) \simeq \left(\frac{10^{-33}}{\eta} \right) \quad (23)$$

Now the bounce at $t = \tau \pmod{\tau}$ must be after the Planck time $t_{Pl} = 10^{-44}s$ when $a(t_{Pl}) \sim 10^{-32}$ and before the electroweak transition at $t_{EW} = 10^{-10}s$ when $a(t_{EW}) = 10^{-15}$. From Eq.(23) this implies for η that

$$10^{27} < \eta < 10^{95} \quad (24)$$

The parameter $f = \hat{a}(t_T)/a(t_T)$ defined at turnaround reappears at the bounce by $\hat{a}(\tau) = fa(\tau)$. Immediately after the bounce there is conventional inflation with enhancement $E = a(\tau)/\hat{a}(\tau)$ and successful inflation requires $E > 10^{28}$. Consistency requires $Ef=1$ and therefore $f < 10^{-28}$. The fraction of entropy jettisoned in deflation immediately after turnaround is at least $(1 - 10^{-28})$.

Four Discussions of Entropy

(i) Entropy at present $t = t_0 \pmod{\tau}$.

Having set up an oscillatory universe by massaging the four terms in our Friedmann equation, Eq.(1), it behooves us to discuss the entropy at different epochs in the cycle, with a view to find the minimal set of assumptions necessary to reconcile cyclicity with the second law of thermodynamics.

Consider first the present epoch $t = t_0$. The contributions of the radiation to the entropy density s follows the relation

$$s = \frac{2\pi^2}{45} g_* T^3 \quad (25)$$

First consider only photons with $g_* = 2$. The present CMB temperature is $T = 2.73K \equiv 0.235meV \sim 1.191(mm)^{-1}$. Substitution in Eq.(25) gives a present radiation entropy density $s_\gamma(t_0) = 1.48(mm)^{-3}$. Using a volume estimate $V = (4\pi/3)R^3$ with $R = 0Gly \simeq \times 10^{29}mm$ gives a total radiation entropy $S_\gamma \sim 6.3 \times 10^{87}$. Including neutrinos increase g_* in Eq.(25) from $g_* = 2$ to $g_* = 3.36 = 2 + 6 \times (7/8) \times (4/11)^{4/3}$. This increases $S_\gamma = 6.3 \times 10^{87}$ to $S_{\gamma+\nu} \sim \times 10^{88}$.

This total entropy is interpretable as $\exp(10^{88})$ degrees of freedom, or in information theory [17] to a number I of qubits where $2^I = e^S$ so that $I = S/(\ln 2 = 0.693) \sim 10^{88}$. This is well below the holographic bound which is dictated by the area in terms of Planck units $10^{-64}mm^2$ which gives $S_{holog}(t_0) = 4\pi(10^{29}mm)^2/(10^{-32}mm)^2 \sim 10^{123}$ about 10^{35} times bigger. In [17] it is suggested that some of this difference may come from supermassive black holes.

The entropy contribution from the baryons is smaller than S_γ by some ten orders of magnitude, so like that of the dark matter, is negligible.

What is the entropy of the dark energy? If it is perfectly homogeneous and non-interacting it has zero temperature and entropy: this is our assumption here. Another viewpoint, at least for a pure cosmological constant, is that one number Λ cannot contain entropy.

Finally, the 4th term in Eq.(1) corresponding to the brane term is negligible, as we have already estimated.

The conclusion is that $S_{total}(t_0) \sim 10^{88}$.

(ii) Entropy at turnaround $t = t_T \pmod{\tau}$.

We have estimated that $a(t_T) = 10^{29}\eta$. The temperature T_γ of the radiation scales as $T_\gamma \propto a(t)^{-1}$ so using the entropy density of Eq.(25) a comoving 3-volume $\propto a(t)^3$ will contain the same total radiation entropy $S_\gamma(t_T) = S_\gamma(t_0)$ as at present; this is simply the usual adiabatic expansion.

The expansion from $t = 0 \pmod{\tau}$ to $t_T \pmod{\tau}$ is, of course, not purely adiabatic because irreversible processes take place. There are phase transitions such as the electroweak transition at $t_{ew} \sim 100ps$, the QCD phase transition at $t_{QCD} \sim 100\mu s$, and recombination at $t_{rec} \sim 10^{13}s$. Further irreversible processes occur during stellar evolution. Although the expansion of the radiation, the dominant contributor to the entropy is close to adiabatic, the entropy of the matter inevitably increases with time in accord with the second law of thermodynamics.

In our model, the entropy of the matter increases between $t = 0 \pmod{\tau}$ and $t_T = 47Gy \pmod{94Gy}$. Even approximating the entropy of the dark energy as zero and the radiation as adiabatic, the matter part represented by ρ_m will cause the entropy to rise from $S(t=0)$ to $S(t_T) = S(t=0) + \Delta S$ where ΔS causes the contradiction plaguing the oscillatory universe for a long time [1–3].

The key point is that in order for entropy to be cyclic, the entropy which was enhanced by a huge factor $E^3 > 10^{84}$ at inflation must be reduced equally dramatically at some point during the cycle so that $S(t) = S(t + \tau)$ becomes possible. Our proposal is that entropy is so reduced, or deflated, at the turnaround $t = t_T$ by jettisoning causally disconnected regions [13] and keeping only a fraction $f^3 < 10^{-84}$ of the entropy. The second law of thermodynamics continues to obtain but other causally disconnected regions are permanently removed from our universe at each turnaround.

(iii) Entropy for contraction $t_T < t < \tau \pmod{\tau}$

The discussion of the entropy is the most interesting during the contraction phase. According to statistical mechanics one expects the entropy to change from $\hat{S}(t_T) =$

$10^{-84}[S(t = 0) + \Delta S]$ to $\hat{S}(\tau) = \hat{S}(t_T) + \Delta\hat{S}$ and that $\Delta\hat{S}$ be positive. At least that is inevitable if the thermodynamic arrow of time remains in the direction of positive t .

There are immediate difficulties. Consider just one of the transitions, the recombination in reverse. For the contracting universe confronting such a phase transition will prematurely bounce if $\Delta\hat{S} > 0$ is maintained.

A consistent possibility that will permit the tiny universe to execute the required transitions in reverse is that

$$\Delta\hat{S} = -10^{-84}\Delta S \tag{26}$$

and then premature bouncing can be avoided.

A way to implement this is to reverse the thermodynamic arrow of time during contraction. We consider this one of the two principal weaknesses of the present picture (see the Final Discussion) but such an assumption is necessary to allow contraction all the way from $t = t_T \pmod{\tau}$ to $t = \tau \pmod{\tau}$.

Because the contracting universe is so small, only a decrease by $\Delta\hat{S}$ given by Eq. (26) is required, but this question requires clarification. We have nothing noteworthy to add.

(iv) Entropy at bounce $t = \tau \pmod{\tau}$

Immediately after turnaround the inflation increases entropy by 10^{84} so $S(t) = S(t + \tau)$ providing Eq.(26) or its alternative is satisfied. The overall symmetry between the initial inflation and the deflation at turnaround are one appealing aspect of this particular version of a cyclic universe.

Final Discussion

The standard cosmology based on a Big Bang augmented by an inflationary era is impressively consistent with the detailed data from WMAP3 [16] when dark energy, most conservatively a cosmological constant, is included.

The objections to this standard model are largely philosophical and not motivated directly by observations. The first objection is the nature of the initial singularity and the initial conditions. A second objection, not of concern to some colleagues, is that the predicted fate of the universe is an infinitely long expansion.

We have attempted to outline a cosmology where these objections are answered. But the proposal has, itself, shortcomings. The two most serious are in our opinion:

- The reversal of the thermodynamic arrow of time during the contraction phase renders our proposal dubious. The fact that the necessary entropy reduction is at most 10^{-84} of the entropy gain during expansion does not address the deeper issue of how entropy decreases.
- One motivation for a cyclic cosmology is the avoidance of spacetime singularities. With regard to the powerful results of [15], their theorem is not immediately applicable because it assumes the average expansion parameter ^{#2} is $H_{av} > 0$ whereas here $H_{av} = 0$. However, this may provide only temporary relief from an ubiquitous difficulty.

We publish the present deflationary proposal mainly in the hope that it will stimulate an improved and more consistent formulation by others.

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^{#2}Given that a quasi-static universe is untenable for reasons of instability, a corollary of the theorem proved in [15] is that the *only* possible infinite lifetime universe is one where $H_{av} = 0$.

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